Feature Extraction and Recognition of Rotational Target under the Sea Background

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Abstract: Considering the impact of sea clutter on target classification and recognition, a method based on RBF is proposed to restrain the actual sea clutter, which can be converted the sea clutter into random noise. After denosing, a S transform time-frequency approach is used to obtain the two time-frequency distribution images. They are helicopter and propeller aircraft images with nosie. Then extracted the invariant moment features of images for target recognition. The simulation results have shown an average accuracy of 85%, which validates the effectiveness of this method.

1 INTRODUCTION

The signals of sea skimming flying helicopters and propeller-driven fixed-wing aircrafts are important types for naval radar to detect and recognize. Helicopters and propeller aircrafts are equipped with large long faster rotating rotors. The rotor blades turning around the rub with periodic high-speed rotation makes rotor and electromagnetic wave of radar interact to produce the periodical change of echo signal in amplitude and phase, which produces a beneficial feature to identify micro-Doppler phenomenon. However, sea clutters are serious constraints on the detectability of target radar echoes from sea surface or near the surface, so target identification in the sea conditions is relatively difficult.

For detection and target recognition of helicopter, domestic and foreign researchers have carried out relevant research work. J. Misiurewicz (Misiurewicz et al., 1997) analyzed various types of helicopters echo data, founding the rotation effects of the rotor blades, so the echo data contained scintillation “pulse” related to rotational speed of the rotor and the number of rotor blade; G. C. Gaunaard (Gaunaurd and Strifors, 1996) made an effective identification of different types of targets based on time frequency distribution by PWVD; Rotander (Rotander and Von Sydow, 1997)proposed to identify the helicopter by the ratio between the radius rotor of and the number of blade, however, the analysis is conducted in an environment which is noise and clutter free; Ding Jianjiang et al., analyzed micro-Doppler effects on rotor aircraft, extracting amplitude, phase, and modulation characteristics of target echo signal from the time domain and frequency domain for the classification and recognition of three types of aircraft.

These studies have not considered target detection of rotating body in complex conditions. Farina (Gini and Farina, 1999) detected the rub echo of helicopter in k distribution clutter background without considering micro-tremor signal. The RCS of helicopter rub is generally small, so this method is only valid for the close-in targets.

In the condition of sea clutter, the spectrum of target echo signal mixes with sea clutter spectrum, and the amplitude of target echo signal is not dominant comparing with amplitude of sea clutter echo. Using traditional frequency or time domain processing approach to analyze the target echo signal interfered by sea clutter is unsatisfactory. Time-frequency analysis converts radar echo signals from one-dimensional time or frequency domain to the joint time-frequency domain for analysis, which can provide richer target information. The approach of frequency analysis based on S-transform has the advantages of Fast Fourier Transform and wavelet transform, avoiding the disadvantages of both. It has

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good time-frequency concentration, and does not contain cross terms (Zhu et al., 2015).

Our proposed framework is shown in figure 1. Firstly, applicable sea clutter filtering method is researched; then, combing target recognition method and spectrogram based on S Transform in the literature; extracting invariant moments from it, thus achieving the recognition, extraction and classification of rotating target under the sea background.

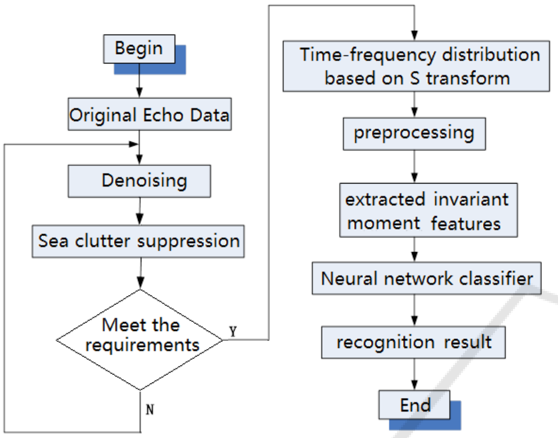

Figure 1: A flow chart of our method.

Detailed steps are as follows:

(1) Pre-process the original target radar echo data by filtering and noise reduction;

(2)Suppress preprocessed echo signal with sea clutter, improving signal-noise ratio;

(3) make s transform for clutter suppressed radar echo signal, obtaining the image of time-frequency distribution;

(4) Preprocess the frequency distribution image with the regularization method;

(5) Extract seven moment invariants features for regularized image, constituting vector with seven dimensions;

(6) Feed the moment invariants eigenvector into the neural network classifier, getting the result by classification and recognition.

2 FILTERING MODEL OF SEA CLUTTER BASED ON NEURAL NETWORK

Traditional description method for sea clutter is to build classical random statistical model. These statistical models can only describe changes in sea clutter from the amplitude; however, the inner dynamic characteristics generated by sea clutter cannot be explained. The literature (Haykin and Puthusserypady, 1997) indicates that quoting chaos theory into the study of sea clutter is necessary and feasible. Use phase space reconstruction theory to obtain internal chaotic dynamics model which produces sea clutter, then adopting neural network to study the inherent laws of sea clutter, after that, use trained neural network to make prediction and cancellation for sea clutter, and transfer the sea clutter data with strong amplitude into random noise signal in strong amplitude, thus achieving the suppression of sea clutter.

The equation of sea clutter in dynamic systems can be described as follow:

$$X(n+1) = \mathrm{H}(X(n)) \tag{1}$$

Through the reconstruction of phase space, the prediction equation of sea clutter can be expressed as:

$$X_{i+m\tau} = F(x_i, x_{i+\tau}, \cdots x_{i+(m-1)\times\tau}) \tag{2}$$

Theoretically, if the analytical solution of the equation is acquired, the predictive value of sea clutter can be worked out, thus, the suppression of sea clutter is realized. But solving the analytical solution is almost impossible. So RBF neural network can be introduced to predict the equation of sea clutter based on the known chaotic time series samples of sea clutter. The schematic diagram of RBF neural network for prediction is shown in Figure 2. In the process of forecasting, introduce the observed value of sea clutter signal at the right side of prediction equation (2) as RBF input. Input unit is m, which means that the number of entered layer is equal to the embedding dimension and RBF network output unit is appropriate prediction value of sea noise.

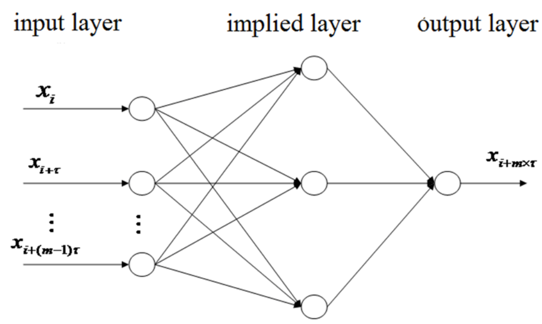

Figure 2: Schematic diagram of sea clutter based on RBF neural network prediction.

Detailed steps of sea clutter suppression based on neural networks are as follows:

(1) Using reconstruction method of phase space to construct n dimensional training data of, where the input data is $X_1 = \{x_1, x_2, \cdots x_{m\times\tau}\}$, $X_2 = \{x_2, x_3, \cdots x_{m\times\tau+1}\}$, $\cdots$, $X_n = \{x_n, x_{n+1}, \cdots x_{m\times\tau+n}\}$. Ideal output data: $Y_1 = x_{m\times\tau+1}$, $Y_2 = x_{m\times\tau+2}$, $\cdots$, $Y_n = x_{m\times\tau+1+n}$.

(2) Training the RBF neural network with training data acquired by the construction of phase space, and working out network structure after training: $Y_i = f(X_i)$, which $X_i = \{x_i, x_{i+1}, \cdots x_{m\times\tau+i}\}$, $Y_i = x_{m\times\tau+1+i}$.

(3) Predicting sea clutter by one-step prediction method, the result can be expressed as $Y_{n+1} = f(X_{n+1}, X_{n+2}, \cdots X_{n+m\times\tau+1})$

(4) Making the predictive value subtract from ideal value of sea clutter data achieving the cancellation of sea clutter $\delta = Y_{n+1} - Y_n$

The actual data of sea clutter is used as simulation data, which length is 1980. Figure 3 shows the waveform of sea clutter after amplitude normalization.

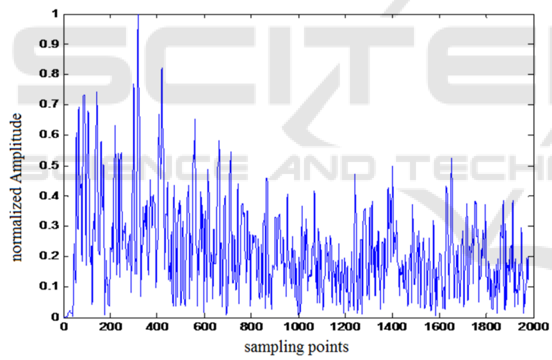

Figure 3: Sea clutter waveform.

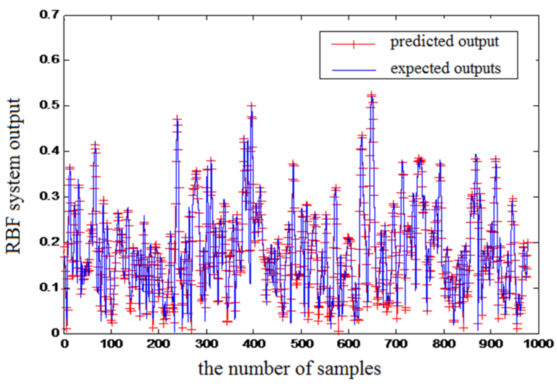

Figure 4: Sea clutter prediction result based on RBF neural network.

Training and predicting sea clutter based on RBF neural network. The first 1000 data from collecting site is used for neural network training, the other 980 is for predicting neural network. With the success of network training, prediction samples is used for network prediction of sea clutter, the result is shown in Figure 4. Network predictionerror, that is, sea clutter cancellation result is shown in Figure 5.

It can be seen from Figure 5 that RBF neural network can realize the prediction and cancellation of sea clutter signal, and transform strong amplitude sea clutter information into weak amplitude random noise signal to realize the suppression of sea clutter.

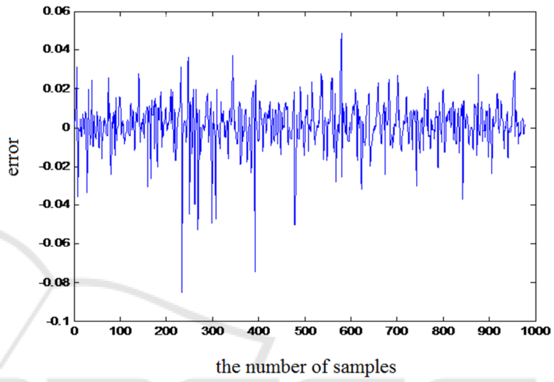

Figure 5: Sea clutter prediction error RBF based on neural network.

3 TIME-FREQUENCY FEATURE EXTRACTION AND TARGET RECOGNITION METHOD BASED ON S TRANSFORM

Due to the non-stationary, non-Gaussian, and time-variation of sea clutter signal, traditional time domain or frequency domain signal processing methods is difficult to take effect on target detection and recognition in the condition of sea clutter. The method of time-frequency analysis converts radar echo signals from one-dimensional time or frequency domain to the joint time-frequency domain for analysis, which can provide richer target information. The time-frequency distribution of radar echo signals can be viewed as an image on the plane of two-dimensional time-frequency distribution, thus the relevant knowledge of image processing can be employed to extract target features. For the image, the moment feature is an extremely valid characteristic, which mainly characterizes the overall shape of the target image with invariant features of rotation, translation, scale and other characteristics. It can effectively reflect the essential characteristics of the image. Time-frequency analysis is used to analyze the target echo signal interfered by sea clutter, and the robust features of time-frequency images produced from various target signal with sea clutter interference are extracted on the time-frequency plane, which is to solve the problem of target identification in the sea condition.

3.1 Time-frequency Analysis of Target Echo Signal

First of all, time-frequency method is used to analyze sea clutter. Measured data of sea clutter in the Figure 3 is converted by S Transform, and the corresponding time-frequency distribution is in the Figure 6. It can be seen from Figure 6, on the frequency plane, sea clutter energy mainly concentrates in the low frequency range, and its energy distribution is dispersed, with good robustness.

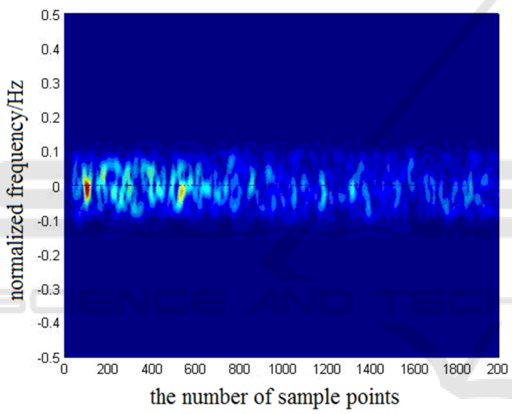

Figure 6: S -Transform frequency spectrums of sea clutter signals.

3.2 Time-frequency Feature Extraction and Target Recognition Algorithm based on S Transform

Moment feature of image usually describes the general shape and characteristic, which main idea is to transform insensitive area- based several moments as shape characteristics, for the identification of target image. For a $M \times N$ size digital image, which the order moment $p+q$ is defined as:

$$M_{pq} = \sum_{i=1}^{M}\sum_{j=1}^{N} i^p j^q f(i,j) \qquad p,q = 0,1,2... \tag{3}$$

$p+q$ central moment is defined as:

$$m_{pq} = \sum\sum (i-\bar{i})^p (j-\bar{j})^q f(i,j) \tag{4}$$

where,

$$\bar{i} = M_{10} / M_{00}, \bar{j} = M_{01} / M_{00} \tag{5}$$

respectively the center of image gray in the horizontal and vertical directions, also known as the centroid. Central moment reflects the distribution of gray scale in the image area comparing with gray center. In order to get invariant features of moment, the definition of central moment is normalized as:

$$\mu_{pq} = m_{pq} / {m_{00}}^r, r = (p+q)/2+1, p+q = 2,3,4... \tag{6}$$

Normalized definition of central moment indicates 7 moment invariants with invariability in translation, scale, and rotation (among which only has translation and scale invariance). The definition is as (7):

$$\begin{cases} \varphi_1 = \eta_{20} + \eta_{02} \\ \varphi_2 = (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2 \\ \varphi_3 = (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2 \\ \varphi_4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2 \\ \varphi_5 = (\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] \\ \qquad + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \\ \varphi_6 = (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] + 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03}) \\ \varphi_7 = (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] \\ \qquad - (\eta_{30} - 3\eta_{12})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \end{cases} \tag{7}$$

Table 1: Eigenvector of two types of targets in model features library.

	Invariant moments of time-frequency distribution based on S transform						
	φ_1	φ_2	φ_3	φ_4	φ_5	φ_6	φ_7
Helicopter	5.9741	14.0975	24.0937	22.7050	46.3632	30.2507	46.5574

Table 2: Classification results.

	Classification rate	
	Air condition（SNR=8dB）	Sea condition（SCR=6dB）
Helicopter	93.33%	90%
Prop	100%	80%
The average recognition rate	96.665%	85%

4 SIMULATION RESULTS

Conduct target echo signal with S Transform separately from helicopter and propeller aircraft; after working out its time-frequency distribution, extract moment invariants feature of image and input them into neural network classifier for classification and identification. For simulation, radar and target parameter are set as same as (Zhu et al., 2015); according to desired SCR (the ratio of signal to clutter), adjust data amplitude of sea clutter, and generate radar echo signal of helicopter and propeller aircraft in sea condition that SCR=6dB. Collect 45 sets of data for the two objectives respectively and randomly choose 15 sets of data as training samples, a total of 30 training samples, another 30 sets of data as a test sample, a total of 60 test samples, using a neural network classifier to predict classification, network prediction results are shown in Fig 7.

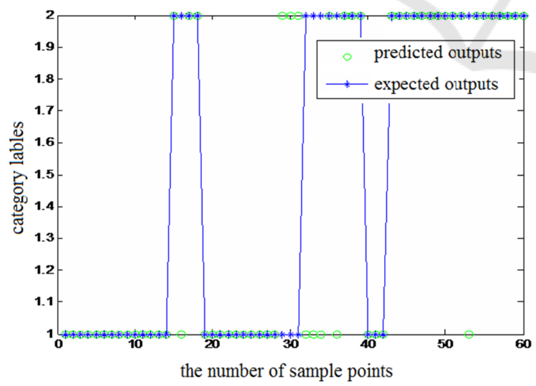

Figure 7: Neural network classifiers results.

Table 1 shows eigenvector (average value) of two types of targets in model library. Figure 2 is based on S Transform reflecting the recognition result of moment invariants features in the time-frequency distribution of target echo signal, which also give the result of target recognition by using the method of signal to noise ratio SNR = 8dB (main interference is Gaussian white noise). The recognition result shows that it is valid to adopt moment invariant feature to detect and recognize the target.

5 CONCLUSIONS

Under the sky background, using time-frequency feature extraction and target recognition method based on S-transform to recognize target can make recognition rate of helicopter to 93.33%, the recognition of propeller aircraft to 100%, and the average recognition rate of two types of targets to 96.665%.

Under the sea ground, sea clutter interference makes target recognition rate decline, but after the introduction of clutter suppression, S-transform based time-frequency feature extraction and target recognition method can also reach 90% and 80% correct recognition rate on helicopters and propeller aircrafts targets, and average recognition rate of 85% correspondingly. Time-frequency feature extraction and target recognition method based on S-transform are more effective for the detection and recognition of helicopter and propeller aircraft with a rotating plane, which are able to reach a certain recognition rate.

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